FISHFATE Users Guide: Spatially Temporally Explicit Population Simulation Model

PURPOSE: The evaluation of alternative environmental windows for dredging operations, which represent a broad spectrum of project and site specific conditions (e.g., type of dredge plant, local hydrodynamics, bathymetry, etc.) requires development of a spatially- and temporally-explicit population simulation model. Unless spatial dynamics are accounted for, exploration of spatial and/or temporal alternatives is impractical and is of limited effectiveness (Pelletier and Magal 1996). Ultimately, an integrated biophysical and population modeling package is needed that contains coupled population-dynamic, hydrodynamic, fate-and-transport, and bioenergetic models that can be applied in spatially-explicit formats. This Users Guide details a population-dynamic model that provides a quantitative biological foundation for such an integrated modeling package.

BACKGROUND: Interagency negotiations of environmental windows for individual dredging projects are frequently handicapped by a lack of information on entrainment effects and an inability to predict the consequences of alternative scenarios. Objective tools are needed to assess alternative environmental windows to assess the actual risk to resources of concern, and to provide guidance to minimize entrainment impacts during dredging activities (Reine and Clarke 1998; Reine et al. 1998). To address this problem, a suite of viable approaches for assessing dredging project scenarios has been identified within a population-modeling framework by Ault et al. (1998a).

This Users Guide details an integrated modeling package, FISHFATE, that assesses alternative environmental windows related to hydraulic entrainment of aquatic organisms. The model was designed and built on a UNIX platform in the C++ language to take advantage of its object-oriented capabilities. The underlying model is called the STOCAST (**S**patial and **T**emporal **O**bject-oriented **C**ohort-**ST**ructured) model (Meester, in preparation). It is a spatial extension of the REEFS model (Ault et al. 1998b) and is compatible with SSFATE (Johnson et al. 2000) and associated models.

MODEL STRUCTURE: The spatial structure of the model is based on subunit grids of variable sizes and overall dimensions based on the waterway or harbor under consideration for dredging and the resolution of the existing data. Each subunit is represented as a unique object and is linked to all adjacent subunits (Figure 1). The population is simulated through a cohort structure comprised of a group of identical individuals (a cohort) where each cohort is uniquely identified by its time step of recruitment, spatial location at recruitment, and sex. Female and male cohorts are treated separately to allow for the easy calculation of egg production and also for the introduction of differential growth, mortality,

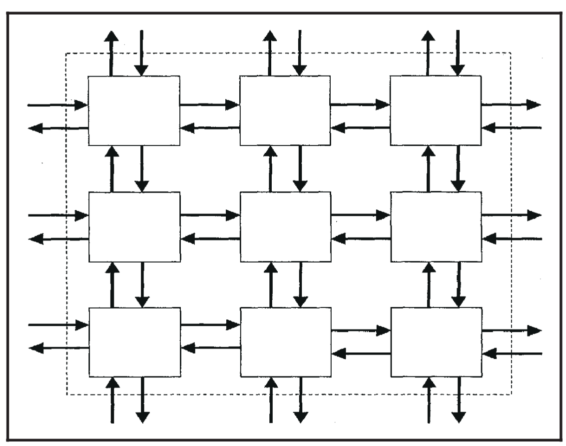

Figure 1. Linking of each grid cell to surrounding grid cells

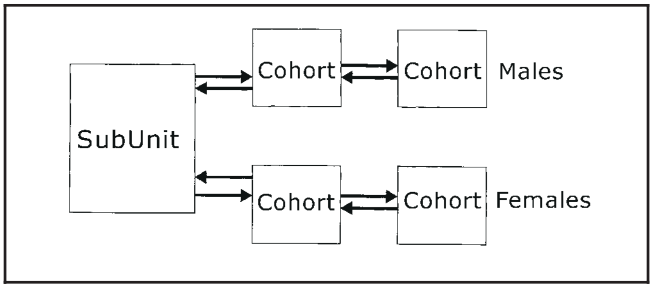

Figure 2. Cohort structure used in FISHFATE

spawning and temporal sex changes if this information is available. Each cohort is linked to a subunit at all times (Figure 2), making each cohort a spatially explicit unit. FISHFATE can be run to simulate any number of finite time steps, from minutes through years, and is capable of simulating any species of fish (temperate, tropical, freshwater, etc.) as well as shellfish and crustaceans.

The grid structure of the FISHFATE model facilitates integration with other spatial modeling packages, specifically those using a grid-based approach (e.g., SSFATE).

USER INPUT FILES

Model Parameters. A 'Parameters.txt' file must be created with all model parameters (one on each line). The parameters requested (in order required in 'Parameters.txt') are as follows:

'Parameters.txt':

StochastVar: =1 for stochastic simulation, =2 for deterministic simulation (see "Simulation")
Seed: seed number for random generator (see "Random Number Generator")
TimeSteps: # of time steps in a year (see "Simulation")
Years: # of years to simulate (see "Simulation")
YearRecruits: total number of recruits for the year (see "Recruitment")
RecTStep: time step at which pulse recruitment occurs (see "Recruitment")
FemRatio: fraction of recruits that are female (see "Recruitment")
RecSwitch: controls recruitment (see "Recruitment")
RecVar: =1 (constant), 2 (one time step burst), 3 (follows Beta Distribution) (see "Recruitment")
BegRec: time step at which recruitment begins (see "Recruitment")
EndRec: time step at which recruitment ends (see "Recruitment")
RecDistType: type of distribution for recruitment (see "Recruitment")
Mswitch: allows for either model determination of M values or user input of values (see "Mortality")
Mmu: natural mortality value (see "Recruitment and Mortality")
MStdDev: natural mortality standard deviation (see "Recruitment and Mortality")
FishMort: fishing mortality rate (see "Mortality")
RecLMax: maximum length of recruits (see "Recruitment")
RecLMean: mean length of recruits (see "Recruitment")
RecLMin: minimum length of recruits (see "Recruitment")
RecLSwitch: =1 (increasing length throughout recruitment), 2 (constant) (see "Recruitment")
LarvalDur: the larval duration from time of spawning to recruitment (see "Recruitment")
LenAtMatM: male length at maturity (see "Recruitment")
LenAtMatSDM: male length at maturity standard deviation (see "Recruitment")
LenAtMatF: female length at maturity (see "Recruitment")
LenAtMatSDF: female length at maturity standard deviation (see "Recruitment")

StockRec: controls the stock-recruitment function if used (see "Recruitment")
LengthCapture: legal minimum size of capture for fishing (see "Mortality")
LenWtAlpha: alpha parameter for length on weight relationship (see "Weight")
LenWtBeta: beta parameter for length on weight relationship (see "Weight")
FecAlpha: alpha parameter for fecundity on weight relationship (see "Fecundity")
FecBeta: beta parameter for fecundity on weight relationship (see "Fecundity")
BegSpawn: time step at which spawning begins (see "Fecundity")
EndSpawn: time step at which spawning ends (see "Fecundity")
SpawnPattern: type of distribution which spawning follows (see "Fecundity")
Linf: L infinity growth parameter (see "Growth")
Kval: K growth parameter (see "Growth")
GrowthStDev: standard deviation of growth relationship (see "Growth")
Tlambda: maximum age in years (see "Growth")
Outputcont: control variable for output (see "Output")
CalCont: control variable for output (see "Output")
OtherCont: control variable for output (see "Output")
LenDistULim: maximum length (mm) category for spatial length distribution output (see "Output")
TotalVessels: total number of fishing vessels (see "Mortality")

Further information on each parameter will follow.

Original Cohort Allocation. Spatial estimates of the distribution of size and densities of each fish species are used to determine the initial population cohort structure. If available, the habitat strata characteristic to a specific waterway or harbor and the population abundance associated with each habitat will be used to estimate abundances at length for species of concern within every subunit defined within the subject area. If habitat and/or spatial population estimates are not available, then the spatial cohort structure will be identified from the best available data. From these estimates, an initial cohort distribution is determined as the initial starting conditions of each model run, or the population structure at time 0. Cohorts are formed by assigning the numbers of fish at 1-cm intervals (splitting them between male and female) within every subunit as a unique cohort. Therefore, the initial population structure at time 0 is comprised of cohorts uniquely identified by subunit, time step (0), sex, and length. The initial cohort structure is input to a file called 'OrigCohorts.txt' and has the following structure (see later section for an example):

'OrigCohorts.txt':

Spatial Subunit ID	Length of Cohort	Number in Cohort
Spatial Subunit ID	Length of Cohort	Number in Cohort
...	...	...
...	...	...

with one length cohort on each line of the input file. The program can handle any number of cohorts, and all three variables are in numeric format.

Dredging Input. Information on dredging types and duration is entered in an input file called 'Dredging.txt' and is described in detail in an ensuing section on "Dredging Mortality."

RANDOM NUMBER GENERATOR (*Seed*)**:** The type of random number generator being used is a full-period linear congruential generator with a period of 2^{31}-1. The generator is seeded with a number between 1 and 2,147,483,647 (*Seed*), which allows for identical reproduction of random numbers in sequence by using the same seed. This is useful for eliminating bias in subsequent model runs due to variation in random number generation. Random numbers can be generated from uniform, normal, exponential, lognormal, gamma or beta distributions. Figure 3 shows the Beta distributions that may be used in the simulation, which are numbered from 1 to 15. There are several options within the model to utilize one of the Beta distributions and the number of the desired distribution should be input where applicable.

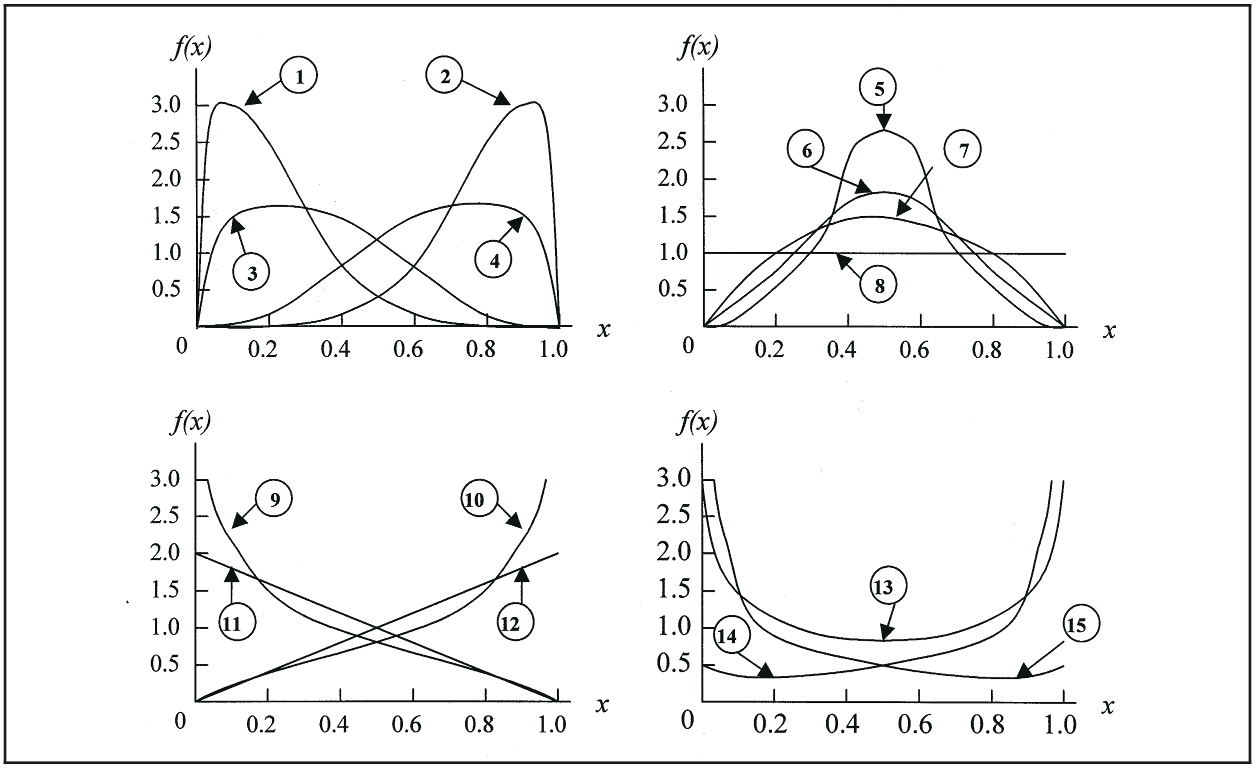

Figure 3. Beta density functions numbered 1-15

SIMULATION (*Years, TimeSteps, StochastVar*)**:** The model can be run using any number of time steps within a year (*TimeSteps*) and for any number of years (*Years*). The number of time steps and recruitment period (see "Recruitment") will determine the number of new cohorts entering the model each year. Setting *TimeSteps* to the following values will simulate different time periods:

TimeSteps	Period
365	daily
52	weekly
12	monthly
1	yearly

To assess the effects of alternative dredging scenarios within a year (differential dredging mortalities due to entrainment during different environmental windows), the model is set to run on daily time steps with output summarized on a monthly basis (see "Output" section). The model is run for 20 years to allow the population to reach an equilibrium state, and the effects of alternative dredging scenarios are assessed in year 20. The model can be run either stochastically or deterministically, and is controlled by the *StochastVar* variable. If *StochastVar* is set to 1, then the simulation is stochastic, and the simulation is deterministic if set to 2.

RECRUITMENT (*YearRecruits*, *RecTStep*, *FemRatio*, *RecSwitch*, *RecVar*, *BegRec*, *EndRec*, *RecDistType*, *RecLMax*, *RecLMean*, *RecLMin*, *RecLSwitch*, *LarvalDur*, *LenAtMatM*, *LenAtMatSDM*, *LenAtMatF*, *LenAtMatSDF*, *Mmu*, *MstdDev*, *StockRec*)**:** There are two different recruitment strategies that may be used in the model: the number of recruits each year is controlled by the user and is constant, or recruitment is tied to egg production of the previous year (i.e., a stock-recruitment relationship is assumed). By setting *RecSwitch*=1, the number of recruits is user controlled, while setting *RecSwitch*=2 will tie recruitment to egg production.

***RecSwitch*=1:** the number of recruits each year is constant and is equal to the number input for *YearRecruits*. There are four options for how recruitment occurs, which are controlled by the *RecVar* variable:

- *RecVar*=1: Recruitment is equally distributed over every time step each year,
- *RecVar*=2: Recruitment occurs at one time step (RecTStep), which is in time step units. For example, if daily time steps are being used, then recruitment would occur on day 30 if *RecTStep*=30.
- *RecVar*=3: Recruitment occurs over a time interval defined by a beginning time step (*BegRec*) and an ending time step (*EndRec*). The temporal distribution pattern is controlled by *RecDistType*, which can take on any of the possible Beta distribution patterns (Figure 3). Set *RecDistType* = to the number of the desired pattern.
- *RecVar*=4: Timing of recruitment is tied to the spawning times (see "Spawning") by the larval duration period (*LarvalDur*). *LarvalDur* is in time step units. If the model is using daily time steps, then the *LarvalDur* variable is in days. Recruitment will then occur at *LarvalDur* time steps after each spawning event during the model run.

***RecSwitch*=2:** the number of recruits each year is tied to egg production.

The number of recruits in a given year is determined by the previous year's stock, and the initial recruitment in year 1 is determined by the stock represented by the initial cohort structure. Several different stock-recruitment relationships may be used, and the choice is controlled by the *StockRec* variable:

StockRec=1: Recruitment is linearly density-dependent on the stock size,

$$R = \beta S_t \text{ (Figure 4a);}$$

StockRec=2: Recruitment is depensatory density-dependent,

$$R = \alpha S - \beta S^2 \text{ (Figure 4b);}$$

StockRec=3: Beverton-Holt relationship,

$$R = \frac{1}{\alpha + \frac{\beta}{S_t}} \text{ (Figure 4c);}$$

StockRec=4: Ricker relationship,

$$R = \alpha S_t e^{-\beta S_t} \text{ (See Figure 4d).}$$

All four options for the *RecVar* variable are still available when using a stock-recruitment function.

The proportion of female recruits is controlled by the *FemRatio* variable (e.g., 0.5). Recruitment is spatially allocated according to the abundance distribution of the original cohorts (see "User Input Files"). For example, if 1,000,000 fish were originally allocated and a particular subunit received 10,000 fish, or 1 percent, of the population, then that subunit would receive 1 percent of the total recruits every year during simulation.

The length of the recruits at the time of recruitment is controlled by several variables. *RecLMin* is the minimum length of new recruits and *RecLMax* is the maximum length of new recruits. If *RecLSwitch*=1, then the length of each new recruit cohort increases from *RecLMin* to *RecLMax* over the recruitment time period each year, assuming that larvae remaining in the water column for longer periods will be larger by the time they recruit. If *RecLSwitch*=2, then the length is pulled from a normal distribution with (*RecLMax*+*RecLMin*)/2 as the mean value. If *RecLSwitch*=3, then recruits all have an initial length=*RecLMean* and is deterministic.

At the time of each new cohort formation (recruitment event) the length at which that cohort will mature is either (a) randomly chosen from a normal distribution, which is ~(*LenAtMatM*, *LenAtMatSDM*) for males and ~(*LenAtMatF*, *LenAtMatSDF*) for females (if a stochastic simulation has been chosen), or (b) the same for all cohorts for a deterministic simulation.

WEIGHT (*LenWtAlpha*, *LenWtBeta*)**:** The weight of each cohort is determined from the species' weight-length relationship:

$$Weight = LenWtAlpha * Length^{LenwtBeta} \tag{1}$$

The weight is not stored as a variable with the cohort, but is determined based on the cohort's length when it is needed for summary statistics.

GROWTH (*Linf*, *Kval*, *GrowthStDev*)**:** Growth is based on a linear version of the Von Bertalanfy growth equation:

$$L_{t+1} = L\,inf\left(1 - e^{-Kval}\right) + e^{-Kval}\ L_t + \varepsilon \tag{2}$$

where L_t and L_{t+1} are lengths at time t and time t+1, respectively, and ε is a random component. For stochastic growth each cohort is created (by recruitment), and for every year thereafter, its growth target for the next year is chosen by randomly drawing the error term in the growth equation (based on *GrowthStDev*) and determining L_{t+1}. The cohort length then increases incrementally towards L_{t+1} over the course of the year. The only stipulation regarding L_{t+1} is that it must be greater than or equal to L_t, to prevent shrinking fish. For deterministic growth, sigma is set to zero and there is no random component to growth.

When a female cohort reaches the length of maturity, it begins to produce eggs during the yearly spawning season. Likewise, when a cohort reaches the size of first capture, it is then susceptible to the spatial *F* value of the subunit that it is contained within.

MORTALITY (*MSwitch, MMu, MStdDev, LengthCapture, Tlambda, FishMort, TotalVessels*)**:** The stock will be subjected to three sources of mortality: natural mortality (M), fishing mortality (F), and dredging mortality (D), based on the following equation:

$$Cohort_{i(t+1)} = Cohort_{i(t)} e^{-(M+F+D)} \tag{3}$$

where $Cohort_{i(t+1)}$ and $Cohort_{i(t)}$ are the numbers of individuals in cohort *i* at time *t*+1 and *t* respectively, and each mortality component is described in detail in the following sections.

Natural Mortality (M)**.** Each cohort will face natural mortality at every time step. There are two options for the control of M:

***Mswitch*=1:** The model determines the natural mortality rate based on the fishes' maximum age (*TLambda*) through the following relation (Ault et al. 1998):

$$\hat{M} = \frac{-ln\left(S\left(t_{\lambda}\right)\right)}{t_{\lambda}} \tag{4}$$

where *S*(*t lambda*)=0.05.

The M mean value (*MMu*) is set and then the *MStdDev* value is determined by choosing a value that sets the upper and lower 95 percent confidence limits at approximately ± 1 year of maximum age.

***Mswitch*=2:** The natural mortality parameters *MMu* and *MStdDev* are the yearly values that are input by the user.

In either case, if growth is stochastic, the natural mortality for a cohort is set at the beginning of each year and is linked to the growth for the upcoming year. This is based on the assumption that slower growing fish will face a higher natural mortality rate, while those growing faster will face a lower mortality. If growth is fixed, then M is also constant. Each cohort is subjected to M at every time step from its birth (time step of recruitment) through its death. A cohort 'dies' when it reaches its maximum age (*TLambda*), or in the case of the original cohorts, the corresponding length at maximum age (since no initial age distribution is assumed).

Fishing Mortality (F). The fishing mortality (*FishMort*) is spatially distributed among the subunits. Each cohort is subjected to the F assigned to the subunit within which it resides at every time step as soon as the cohort reaches the minimum size of capture (i.e., the length of the cohort is >= *LengthCapture*). The F values for each subunit are determined based on the assumption that the following equation holds:

$$F = \overline{q}_s \, (f_1 + f_2 + \ldots + f_n) \tag{5}$$

where $\overline{q}_s$ = catchability coefficient per subunit containing fish and the f_i is the number of fishing vessels fishing in subunit i, where $i = 1$ to n, the total number of subunits with fish. The total number of fishing vessels (*TotalVessels*) is equally distributed among those subunits which contain the species of interest, resulting in an equal distribution of fishing mortality among the stock.

Dredging Mortality (D). Estimates of entrainment rates and mortality of biota (e.g., fish and shellfish life stages) are based on some measure of exposure to the effects of hydraulic entrainment. Exposure time is calculated from the time a target organism will be in a dredge "search area" (i.e., subject to the influence of cutterhead or draghead intake flow fields). End-of-the-pipe mortality is a function of several variables (e.g., extent of entrainment exposure, organism size, behavioral responses, etc.). The mortality imposed by dredging activity (D) is determined from the following relationship:

$$D_{ld} = \left(a_{ld} * s_{ld} * m_{ld}\right) \, f_d \tag{6}$$

where D_{ld} is the dredging mortality imposed by dredge d on cohorts of length l, a_{ld} is the availability of cohorts of length l to dredge d, *s*ld is the selectivity (or entrainment rate) of dredge d to cohorts of length l, m_{ld} is the entrainment mortality of dredge d on cohorts of length l, and f_d is the nominal dredging effort of dredge d. The dredging mortality rate (D_{ld}) is determined for each subunit depending on dredging effort and the availability of cohorts. Cohorts will be subjected to dredging mortality within those subunits in which dredging is occurring. Multiple dredges and dredge types may be modeled, as well as moving dredges.

The entrainment rates of the dredges will be influenced at the gear/organism scale by flow fields, gear dimensions, operating characteristics, habitat types, and mechanical effects on life stages. These entrainment process parameters impact the end effect of dredges on organisms, i.e., entrainment mortality, but the data necessary to describe the linkages of many of these parameters (e.g., draghead or cutterhead surface area, head penetration, dredging depth, net head velocity, etc.) to entrainment mortality are lacking at present. As more specific information becomes available, those impacts may be easily incorporated into the FISHFATE model, but at present, entrainment rates must be estimated from past studies on similar gear types/species, without regard for dredge-specific mechanical and engineering parameters.

The information necessary to simulate dredging activities is input in a file called 'Dredging.txt' which has the following format:

'Dredging.txt':

Number of Dredges
Dredge number (1-Number of Dredges)
Number of lines in dredge selectivity matrix

length	entrainment rate
...	...
...	...

Number of lines in mortality matrix

length	mortality rate of entrainment
...	...
...	...

Number of lines in effort matrix

timestep begin	timestep end	subunit	proportion of timestep running
...	...	...	...
...	...	...	...

Repeat for each dredge type.

A length value of 0.1 is input to represent entrainment and mortality rates for eggs and a value of 0.2 for larvae.

FECUNDITY (*FecAlpha, FecBeta, BegSpawn, EndSpawn, SpawnPattern*)**:** Fecundity is determined by a generalized continuous power function (Ault 1985):

$$\zeta(j,t) = FecAlpha\left(W(j,t)\right)^{FecBeta} \tag{7}$$

where $\zeta(j,t)$ = production of viable ova of a female fish aged j at time t, $W(j,t)$ = the weight of the fish, and *FecAlpha* and *FecBeta* are coefficients. Individuals are assumed to spawn once, with the total spawning output of the subunit being spread out over the time period between *BegSpawn* and *EndSpawn*, according to the Beta distribution type designated by *SpawnPattern*.

MOVEMENT: The model can accommodate several different movement strategies for a species of fish, ranging from no movement at all to constrained random movement. If no movement is assumed, then the cohorts never move from the subunits into which they are recruited. Cohorts may also move freely among subunits at a given rate of movement. Movement patterns will be based on existing data for each species, and different movement scenarios can be run (e.g., migration events). Home ranges may also be set for a species if a cohort is assumed to move within a circle of a given diameter, i.e., a home range.

Home Ranges. To simulate a home range for a cohort, the average amount of time a cohort spends outside the boundaries of a subunit is determined for a given home range. This is done by saturating a subunit with equally spaced cohorts and then geometrically determining the portion of each cohort's home range lying outside the boundaries of the subunit. The assumption is made that fish spend equal amounts of time in all portions of their home range, i.e., that the portion of the home range outside the subunit boundaries equates to the proportion of time spent outside the boundaries. This assumption is backed by evidence (Zeller and Russ 1998). An average value for all cohorts within the subunit is determined, resulting in the average proportion of time a cohort spends outside the boundaries of a subunit. The average value is used because the actual location of a cohort within a subunit is unknown. The simplifying assumption of uniform habitat distribution along the boundaries of each subunit is made since such detailed information is unavailable.

Constrained Random Movement. The constrained random movement module allows cohorts to move freely among subunits. At the beginning of the model run, each subunit is given a desirability index (DI) of 1.00, and the biomass in the subunit is calculated and stored. Throughout the model run, as cohorts move from one subunit to another, the changes in biomass are calculated and the DI changes inversely and proportionately to the change in biomass, i.e., if the biomass of cohorts in a subunit increases by 30 percent over its original biomass, then the DI decreases by 30 percent. At every time step, each cohort is allowed to move at most, one subunit (1 km away), resulting in a range of movement from 1 km to 3.13 km in a time step (Figure 4). Each cohort randomly searches the four adjacent subunits for a subunit that it can move into. The chance that a cohort moves into an adjacent subunit is determined based on a comparison of the current subunit's DI and the adjacent subunit=s DI and is based on a logistic function:

$$\%\ Chance\ of\ \ Moving = \frac{1}{1+e^{\left(-2.5^{*}\left(d_i-1\right)\right)}} \tag{8}$$

where d_i = the ratio of the adjacent subunits DI over the current subunits DI.

OUTPUT (*OutputCont, CalCont, OtherCont*): Summary information is output to two files, called 'SpatialData.txt' and 'TemporalData.txt', each containing similar information. The 'SpatialData.txt' file contains information for each grid unit within the area of interest, while the 'TemporalData.txt' file contains system-wide summary information on a temporal basis (i.e., daily, monthly, etc.). The output is controlled by the following variables: *OutputCont*, *CalCont*, and *OtherCont*.

***OutputCont*=1:** time steps are daily and there are 365 days in a year.
CalCont=1: Summary information is output only at the end of every year.
CalCont=2: Summary information is output at the end of the sixth month and the end of the year.
CalCont=3: Summary information is output at the end of every month.

***OutputCont*=2:** time steps are other than daily and the number of time steps in a year is determined by the *TimeSteps* input variable. Summary information is output every *OtherCont* time steps every year.

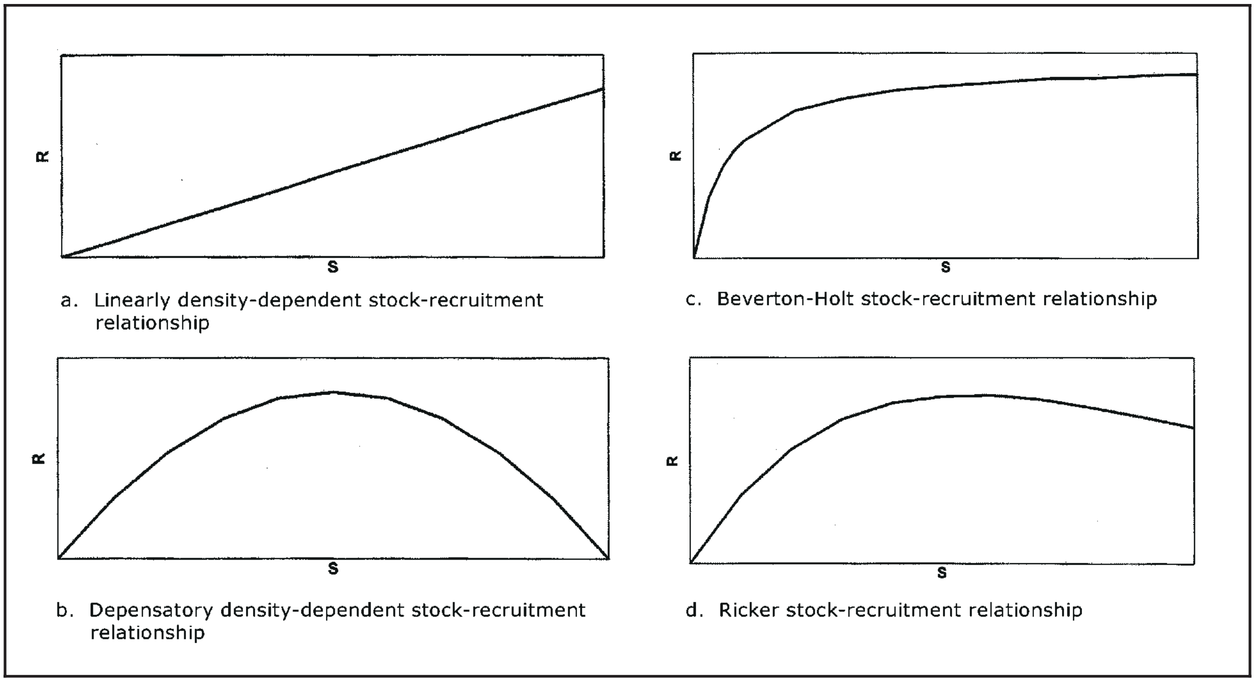

Figure 4. Stock-recruitment relationships available in FISHFATE

The 'TemporalData.txt' file contains the following information:

Total #: the total number of individuals in the entire area
Pre-Exp: the number of pre-exploitable phase individuals in the area
Tot Bio: the total biomass of the stock
D: the dredging mortality rate
EggsL: the number of eggs lost to dredging
Larv: the number of larvae lost to dredging
Juv: the number of juveniles lost to dredging
Adu: the number of adults lost to dredging
SSB: the spawning stock biomass of the stock
YieldN: the yield in numbers for the fishery
YieldW: the yield in weight for the fishery
Lbar: the average length in the exploitable phase of the stock
Lbar(c): the average length in the catch
AveWt(c): the average weight in the catch
EggsP: the number of eggs produced by the stock

The 'SpatialData.txt' files contain the same information with the addition of the number of fishing vessels operating in the grid and the fishing mortality rate in the grid. Examples of both output files are shown in the next section.

EXAMPLE: The following is an example showing input and output files for a simulation run for yellowtail snapper in a hypothetical port in the Florida Keys. Figure 5 shows the input files, 'Parameters.txt', 'OrigCohorts.txt', and 'Dredging.txt', while Figure 6 shows the output files, 'TemporalData.txt' and 'SpatialData.txt'. The simulation is run using daily time steps and encompasses a 20 unit grid system with two dredges operating during the year. The first dredge operates in grid 103 for the first two months of the year and then in grid 109 for the next two months. The second dredge operates in grid 113 for the last four months of the year.

'Parameters.txt'

```
2
88888888
365
20
10700000
155
.5
1
2
155
155
8
1
.2
.00001
0.25
9
7
2
2
34
230
5
230
5
304.8
.0000775
2.7180
500000.5
2.581
130
130
2
546.03
```

'Dredging.txt'

```
1
6
.1    0.32
.2    0.45
12    0.90
18    0.65
24    0.45
60    0.20
6
.1    0.86
.2    0.89
12    0.60
18    0.75
24    1.00
60    1.00
2
0     60    103   0.33
61    92    109   1.00

2
4
12    0.70
18    0.55
24    0.25
60    0.10
4
12    0.70
18    0.95
24    1.00
60    1.00
2
244   365   113   0.67
```

'OrigCohorts.txt'

```
101    20     0.05
101    40     0.06
101    50     0.14
101    60     1.10
101    70     1.25
101    80     0.79
101    90     1.41
101   100     3.19
101   110     1.30
101   120     5.62
101   130     8.23
101   140     8.63
101   150    20.43
101   160     6.29
101   170     8.91
101   180    10.78
101   190     2.22
101   200    20.50
101   210     5.95
101   220     6.20
101   230     6.78
```

Figure 5. Examples of input files for FISHFATE

'TemporalData.txt'

				******Dredging******											
Mo	Total #	Pre-Exp	Tot Bio	D	Eggs	Larv	Juv	Adu	SSB	YieldN	YieldW	LBar	LBar(C)	AveWt(C)	Eggs(x1,000,000)
1	21716428.06	19228794.96	4040.69	0.14	1684	3492	1563	894	3538.41	322902.36	173.56	330.91	327.58	0.53	108503.3
2	26103776.75	20396920.07	5715.95	0.18	1956	3894	1864	1026	4677.59	980296.10	565.68	341.43	336.04	0.57	321844.7
3	29171088.39	23290438.67	7431.55	0.21	9583	8319	4501	2305	6393.70	1522969.89	988.01	368.32	350.33	0.64	590911.5
4	31397202.00	23278414.33	9231.55	0.05	864	2643	469	364	8193.70	1780005.79	1249.98	370.22	359.31	0.68	963872.5
5	32845528.10	23278414.33	10795.93	0.00	0	0	0	0	9758.08	2170971.25	1605.40	378.18	365.66	0.72	1420111.7
6	33804280.15	23278414.33	12061.44	0.00	0	0	0	0	11023.58	2406763.97	1881.24	385.38	372.59	0.75	1924599.6
7	34451438.48	23278414.33	13044.24	0.00	0	0	0	0	12006.39	2549084.02	2079.86	390.98	377.87	0.78	2426832.7
8	34897250.53	23278414.33	13791.43	0.00	0	0	0	0	12753.57	2634979.19	2215.65	395.17	381.51	0.81	2886798.2
9	35210899.00	23278414.33	14355.07	0.12	1684	3492	1563	894	13317.22	2686817.15	2305.16	398.27	383.90	0.82	3283544.9
10	35436067.45	23278414.33	14780.24	0.21	9583	8319	4501	2305	13742.38	2718073.58	2362.72	400.57	385.44	0.83	3612804.4
11	35600928.38	23278414.33	15102.69	0.04	864	2643	469	364	14064.83	2736952.86	2399.04	402.29	386.41	0.83	3879561.5
12	35722841.50	23278414.33	15347.20	0.09	1956	3894	1864	1026	14309.35	2748364.82	2421.64	403.58	387.02	0.84	4092923.0

'SpatialData.txt'

				*******Dredging********														
Mo	Grid	Ves	F	D	Eggs	Larv	Juv	Adu	Total #	Pre-Exp	Biom	SSB	YdN	YdW	LBar	LBar(C)	AvW(C)	Eggs(x1,000,000)
1	101	13.05	0.29	0.00	0.00	0.00	0.00	0.00	224.21	199.02	0.04	0.04	3.93	0.00	330.56	327.46	0.53	1109846.5
1	102	13.05	0.29	0.00	0.00	0.00	0.00	0.00	5566.89	4941.31	1.03	0.90	97.75	0.05	330.61	327.58	0.53	27713342.0
1	103	13.05	0.29	0.54	5890	3400	968	120	1310.54	1163.28	0.24	0.21	23.01	0.01	330.60	327.57	0.53	6519271.0
1	104	13.05	0.29	0.00	0.00	0.00	0.00	0.00	2659.96	2361.06	0.49	0.43	46.71	0.03	330.61	327.57	0.53	13239080.0
1	105	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5659.03	4942.68	1.09	0.96	0.00	0.00	332.38			28851298.0
1	106	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3667.26	3203.05	0.70	0.62	0.00	0.00	332.37			18690692.0
1	107	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8705.68	7603.67	1.67	1.47	0.00	0.00	332.37			44376832.0
1	108	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13054.05	11401.60	2.51	2.21	0.00	0.00	332.37			66546976.0
1	109	0.00	0.00	0.12	1368	1269	359	47	31380.90	27408.56	6.02	5.31	0.00	0.00	332.37			159969424.0
1	110	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18361.84	16037.49	3.52	3.11	0.00	0.00	332.38			93611008.0
1	111	13.05	0.29	0.00	0.00	0.00	0.00	0.00	17534.12	15563.76	3.24	2.84	307.89	0.17	330.61	327.58	0.53	87284336.0
1	112	13.05	0.29	0.00	0.00	0.00	0.00	0.00	12398.95	11005.69	2.29	2.01	217.72	0.12	330.61	327.58	0.53	61721312.0
1	113	13.05	0.29	0.26	2796	2673	780	97	5679.43	5041.21	1.05	0.92	99.73	0.05	330.61	327.58	0.53	28275730.0
1	114	13.05	0.29	0.00	0.00	0.00	0.00	0.00	5036.72	4470.71	0.93	0.82	88.45	0.05	330.61	327.58	0.53	25079976.0
1	115	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8794.00	7680.80	1.69	1.49	0.00	0.00	332.38			44832076.0
1	116	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7651.98	6683.36	1.48	1.29	0.00	0.00	332.38			39013840.0
1	117	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5800.50	5066.24	1.11	0.98	0.00	0.00	332.38			29571424.0
1	118	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13926.94	12164.01	2.67	2.36	0.00	0.00	332.37			70990368.0
1	119	0.00	0.00	0.00	0.00	0.00	0.00	0.00	28397.95	24803.22	5.45	4.80	0.00	0.00	332.37			144759184.0
1	120	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12212.96	10666.99	2.34	2.07	0.00	0.00	332.38			62263076.0

Figure 6. Examples of output files for FISHFATE

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